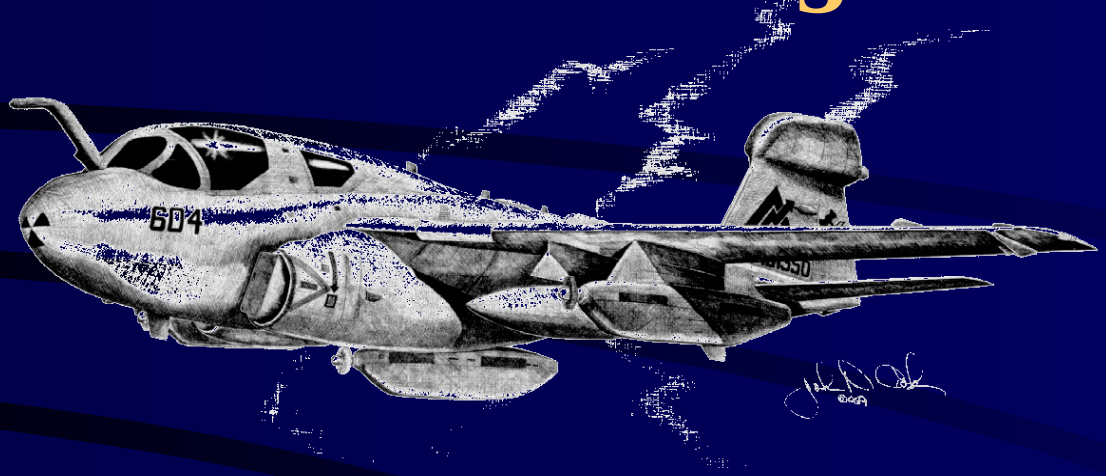
Application of RCM Analysis to Corrosion Failure Modes on the EA-6B Prowler Program



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EA-6B Description

- Electronic Warfare Platform
- Carrier based
- Operated by USN and USMC
- Main Bases:
  - MCAS Cherry Point, NC
  - NAS Whidbey Island, WA
- Extended deployments across the world

Existing EA-6B Maintenance Program

- Squadron level inspection packages
  - FH and calendar based
- Standard Depot- Level Maintenance (SDLM)
  - At depot facility
  - Induction based on condition based inspection (ASPA)
  - 3 to 10 year interval
  - Extensive disassembly – 9 to 12 month TAT
  - Strip and paint

Existing EA-6B Maintenance Program

- Corrosion Inspections
  - 28 Day zonal
  - 224 Day cockpit (seats removed)
- Extensive corrosion repair at SDLM

Integrated Maintenance Concept (IMC)

- CNO directed transition from SDLM to IMC for most USN and USMC aircraft
  - Unpredictable and under funded depot maintenance budgets
  - Perceived worsening material condition
- IMC
  - Fixed, calendar-based depot induction schedule
  - Based on Reliability-Centered Maintenance (RCM)

RCM Analysis

- RCM is an analytical process used to determine preventive maintenance requirements for a physical asset in its operating environment [1]

[1] Society of Automotive Engineers Standard SAE JA-1011, *Evaluation Criteria for Reliability-Centered Maintenance Processes* (August 1999)

- Objective is the most cost effective maintenance program for a required level of safety and operational availability
- Evaluates alternatives to prevent or mitigate equipment failure modes

EA-6B IMC Program

- Traditional squadron level maintenance packages
  - Calendar and FH based
- Depot level events performed in squadron spaces
  - 2 year intervals
  - 2-3 week duration
- Depot Induction
  - 8 year cycle
  - Scope similar to SDLM

EA-6B Corrosion Analysis

- Evaluation of existing corrosion control program
  - 28 day inspection zonal in nature: effort spent on areas that were not corrosion prone or slow growing
  - “Correction” often worse than corrosion
    - Small areas of corrosion mechanically removed along with larger portions of protective coating
    - Usually replaced with inferior coatings
  - More frequent inspections limited to accessible areas
  - Repair of “severe” discrepancies deferred due to operational requirements

EA-6B Corrosion Analysis

- Evaluation of existing corrosion control program (continued)
  - 28 Day inspection required opening of sealed areas at sea
  - Normal “wear and tear” from 28 day inspection (chipped paint, damaged panel seals, etc.) promoted corrosion
  - Frequency and depth of 28 day inspection had significant impact on aircraft operations
  - Existing maintenance program focused on detection and correction vice prevention

EA-6B Corrosion Analysis

- In summary:
- The existing inspection cycle would find and correct corrosion before it became “critical”, but…
  - Most of the effort was spent on the inconsequential
  - Many aspects of the current approach were harmful
  - Very little effort on prevention
- Note: None of this is a knock on the maintainers; they were doing exactly what they were supposed to do and what they were trained to do.

EA-6B Corrosion Analysis

- Approach
  - Evaluate general corrosion inspection interval
  - Identify individual solutions to specific corrosion prone areas
- Use RCM analysis

General Corrosion Inspection Interval

- RCM analysis analyzes individual failure modes
- Analyzed a general corrosion failure mode for each zone inspected in the 28-day inspection
- Analysis of discrepancies found during 28-day inspection revealed the following:
  - Most did not affect safety or structural integrity in any way
  - Most were not fast growing
  - Most would not be significantly more costly to repair even if left uncorrected for periods of time much longer than 28 days
  - Safety of flight, fast growing, or costly failure modes were analyzed separately

General Corrosion Inspection Interval

- Inspection interval is a function of potential to functional failure Interval (Ipf)
- Ipf is the time between when a failure mode becomes detectable until some function of the equipment is lost
  - Example: Crack in a piece of structure, Ipf is the time it takes a crack to grow from detectable until the structure can no longer sustain is intended loads

General Corrosion Inspection Interval

- Applying RCM principles to the failure modes found during a typical 28-day inspection:
  - Loss of a function due to corrosion from detectable is usually in terms of years not weeks
  - For RCM purposes functional failure due to corrosion is defined as the point at which repair cost/effort become significant
    - Always before safety is affected
    - Usually before operations are affected

General Corrosion Inspection Interval

- Based on Ipf of general corrosion failure modes, we concluded the general corrosion inspection could be extended to anywhere from 6 to 18 months
  - Maintenance and failure data
  - Other Naval aircraft (56-308 days)
    - No correlation between condition and inspection interval
  - A-6E 180-day inspection trial

General Corrosion Inspection Interval

- Analytical Interval of 6-18 Months
- Selected 364-Day interval for Implementation
  - Best fit for work-up/deployment cycles
  - Alignment with IMC events
  - Shortest interval that would all but eliminate deployed inspections

Specific Corrosion Prone Areas

- Five areas that required significant action other than inspection during the 364-day inspection
  - Lower Longeron in NLG wheel well
  - Upper Longeron in Cockpit
  - Cockpit Floor
  - Tail fin Pod
  - Honeycomb structure
- Other areas were analyzed as specific failure modes but did not warrant attention beyond the 364-day inspection

Lower Longeron in NLG Well

- Exposed
- Water collects in channel
- Portions not accessible
- Solution:
  - CPC applied during IMC events (2-year interval)

Upper Longeron in Cockpit

- Exposed area
- Water collects in channel
- Portions not accessible
- Solution:
  - CPC applied during IMC events (2-year interval)
  - Inspection/repair at depot IMC event

Cockpit Floor

- Rain/salt spray/standing water in cockpit
- Floorboards and sub-floor
  - Linkages, tubes, wires between make repair problematic
  - Accessible only with seats removed
- Existing paint system inferior
- Solution:
  - CPC applied during IMC events (2-year interval)
  - Improved paint system during IMC depot event

Tailfin Pod

- “Sealed” compartment with lots of faying surfaces (skin to ribs/brackets, etc.)
- Close quarters/packed with electronic equipment
- Sealing not completely effective
- Tails parked over the side aboard ship
- Solution:
  - Penetrating CPC applied during 364-day inspection

Honeycomb Core Structure

- Flight control surfaces/skin panels
- Water entrapment/corroded core
- Extensive Corrosion repairs during SDLM
  - High component scrap rates
- Tap test performed at SDLM/ASPA
  - No specific requirement
  - Usually done as standard maintenance practice
- Solution:
  - Tap test at IMC events (2-year interval)

Corrosion Preventive Compounds

- CPC Products selected by application
  - Hard film for exposed/standing water areas
  - Water displacing fluid film for tailfin pod
- Individual products selected based on:
  - Maintainer experience with classes of products
  - Supply availability
  - HAZMAT issues
  - Experience of other Programs
  - Study that concluded most often used products are all similarly effective if reapplied periodically[1]

[1] Phillip L. Jones, F. Hadley Cocks, Duke University and Thomas Flournoy, FAA Technical Center, *Performance Evaluation of Corrosion Control Products*

Corrosion Analysis – Final Thoughts

- Skyflex seals incorporated
  - Improved sealing
  - Better maintainability
- RCM is a continuous process
  - Includes monitoring
  - Any deficiencies in the analysis will be addressed over time

Results Overview

- RCM Analytical Results
- Actual Results Comparison
- Material Condition Assessment

RCM Analytical Results

- PM tasks developed with MMH and EMT
- Tasks packaged at 28, 56, 364 day
- Tabulated package MMH and EMT showed decrease
  - Packaged changes
  - 2 year cycle

RCM Analytical Results

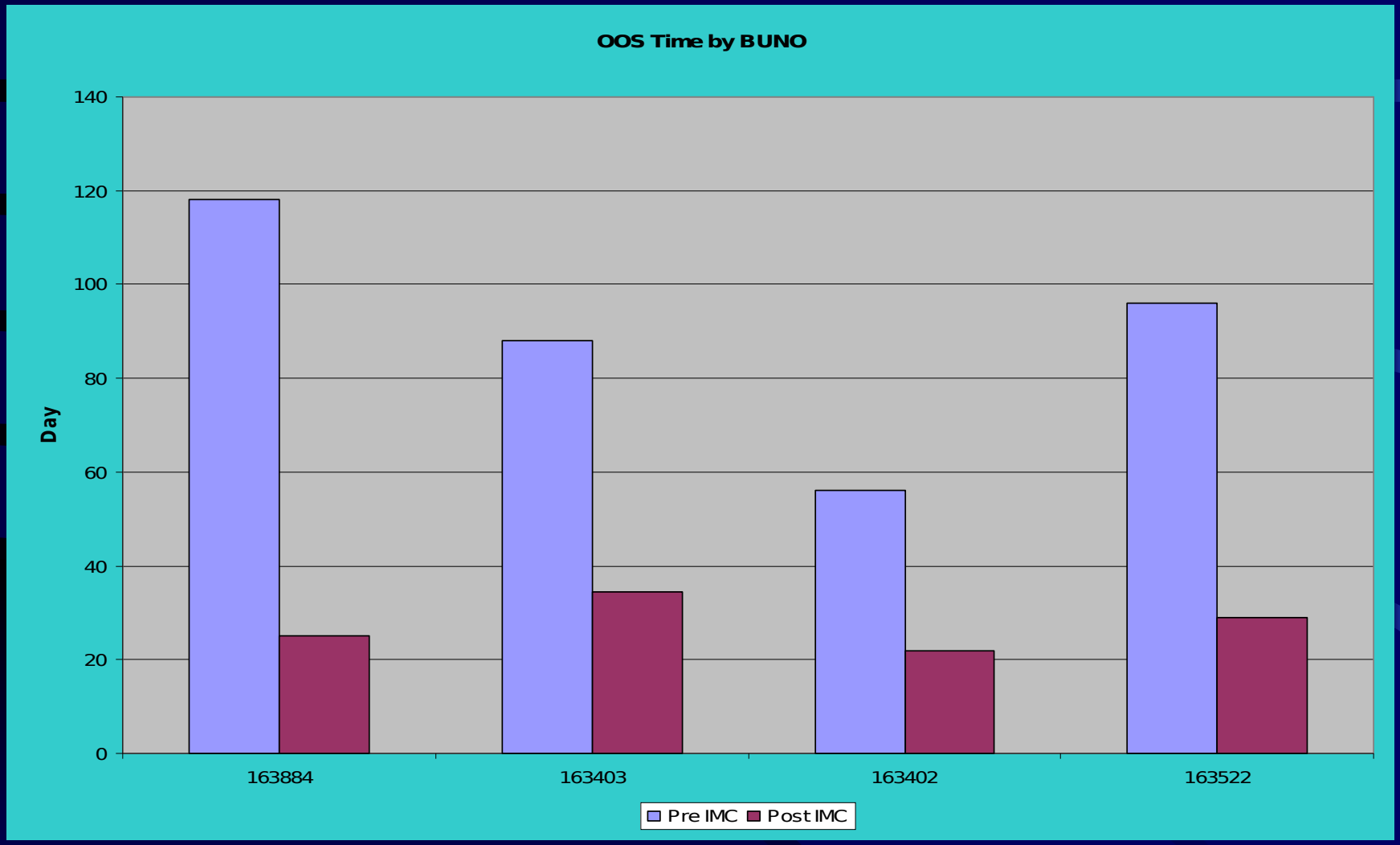
	INTERVAL (DAYS)	INTERVAL WORKLOAD (MMH)	2 YR CYCLE (MMH)	INTERVAL OOS TIME (DAYS)	2 YR CYCLE (DAYS)
Pre IMC	28	93	4836	3	156
	56	126	6552	5	260
	224	194	2328	5	60
		SUM	13716	SUM	476
IMC	28	14	728	0.5	26
	56	11	572	0.5	26
	364	200	1600	5	40
		SUM	2900	SUM	92
		DECREASE	78.86%	DECREASE	80.67%

Actual Data

- Goal: Validate RCM interval
  - Assess Material Condition
  - Assess Fleet Impact
- Prototype one squadron with detailed reports
- Pull multiple types of data
  - OOS, prevention, correction, formal and informal feedback
  - Specific data is essential

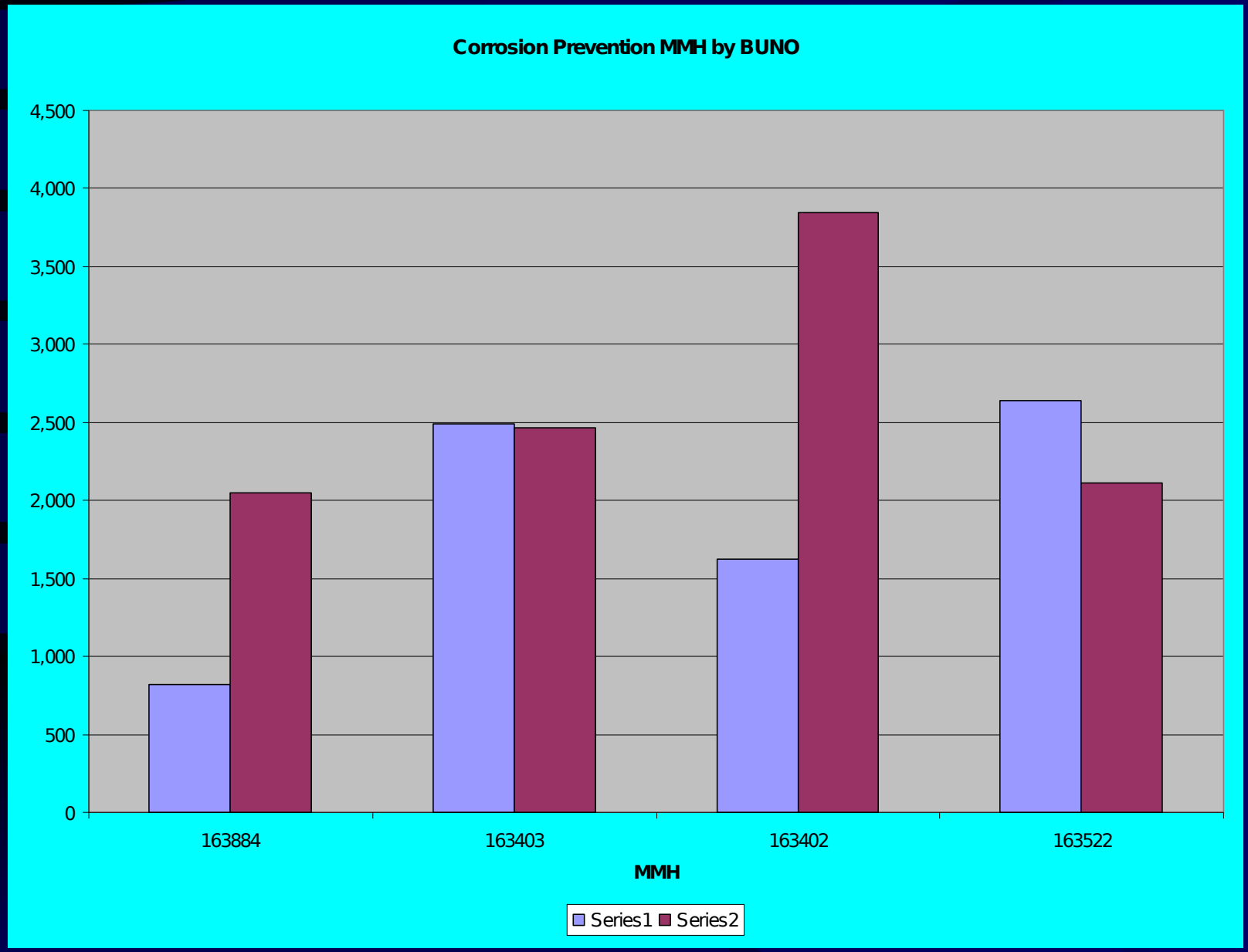
OOS Time

- 28, 56 day tasks proved shorter
  - MMH, EMT decrease
- Larger 364 day event similar in scope and performance time to old 224 day event
- Positive fleet feedback


OOS Time by BUNO
Day
140
120
100
80
60
40
20
0
163884
163403
163402
163522
Pre IMC
Post IMC

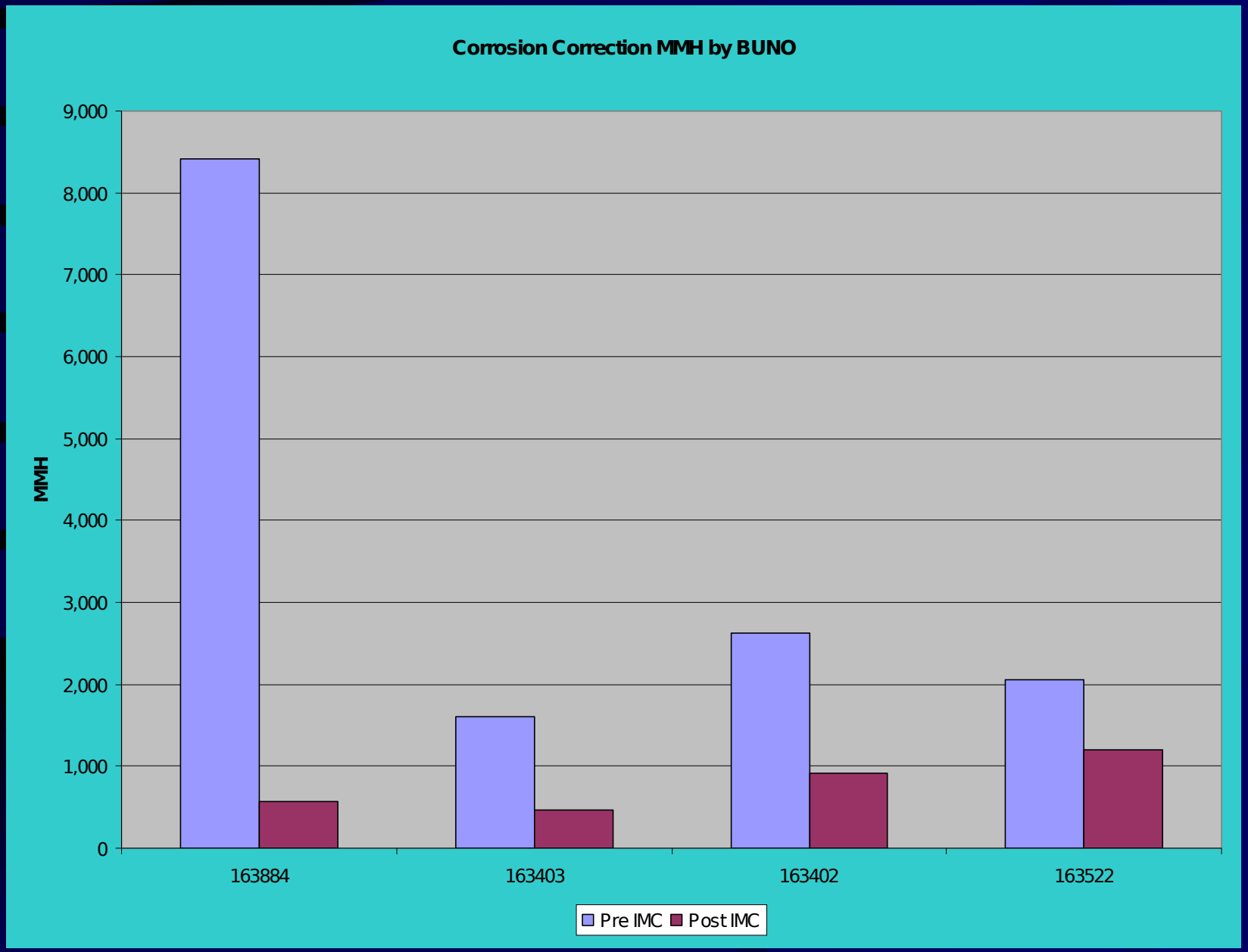
Corrosion Prevention

- Upward MMH trend
- Based on a number of reasons
  - Squadron deployed
  - Lube and wash cycles increased
  - Constant number of personnel
- Overall MMH decrease (correction, OOS, prevention considered)


Corrosion Prevention MMH by BUNO
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
163884
163403
163402
163522
MMH
Series1
Series2

Corrosion Correction

- Significant drop in MMH
- Fewer inspections
  - New packaging of tasks eliminated repeated corrections outside 364 day event
- Material condition maintained
  - Corrosion defects are the “usual suspects”
  - Not significantly worse


Corrosion Correction MMH by BUNO
MMH
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
163884
163403
163402
163522
Pre IMC
Post IMC

Formal Fleet Feedback

- VAQ 140 deployment
  - Formal reports generated
- 5 day turnaround
  - Not including hangar space delays
- No significant problems or gripes
  - Material condition quoted as “surprisingly good”
- Ejection seat surveys submitted
  - More scrutiny, as failure modes are safety related

Informal Fleet Feedback

- Inspection driven OOS times decreased
- Material condition equivalent
- Skyflex application
- Ease of scheduling with fewer major inspections

Conclusions

- Changes to Maintenance Program have been effective
- General corrosion inspections shorter than 180 days should be re-evaluated
- No magic bullets
  - RCM approach of fixing one specific problem at a time provides optimum solutions
- RCM Program must be maintained

Ongoing Issues

- Formalize material condition assessment
- CPC application options/areas
- More prototypes
- 2 year cycle review
- Additional detail on heavy hitters